A Work Project, presented as part of the requirements for the Award of a Master Degree in Management from the NOVA – School of Business and Economics:

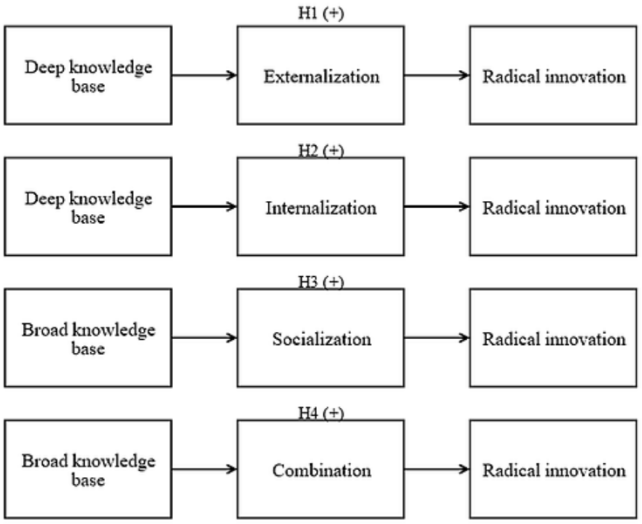
How does a company's existing knowledge base result in radical innovation? An empirical study of Dutch companies in the Life Sciences and Health-industry.

Author:	Stephanie van Bebber
Student number:	3052
ID number:	25667
Supervisor:	Luis Lages
Track:	Masters in Management (Double Degree with Maastricht)

Abstract

The main objective of this thesis is to test how a company's existing knowledge base results in radical innovation, proposing four behavioural process as mediators. Companies with broad knowledge seem to lack sufficient coordination to successfully complete an innovative process. This study proposes that combination and socialization are behavioural processes that could create new combinations of existing knowledge to detect new, unseen patterns to achieve radical innovation. Vice versa, the depth of knowledge could hinder a company, as it could mean that they lack the experience to tackle potential problems in the implementation phase. Furthermore, the depth of knowledge often leads to observational slowness. Therefore, externalization and internalization are proposed behavioural processes that serve as mediators to overcome these challenges and achieve radical innovation consequently. The conceptual model can be found below. These relationships are tested empirically on a sample of Dutch companies in the Life Sciences and Health Industry. The results and conclusions drawn from this study makes valuable contributions to both literature and practice. No significant mediating effect of internalization was found between a company's deep knowledge base and radical innovation, nor the mediating effect of socialization between a company's broad knowledge base and radical innovation. Nevertheless, significant results show that externalization partially mediates the relationship between a company's deep knowledge base and radical innovation and combination mediates the relationship between company's broad knowledge base and radical innovation. In conclusion, this study provides concrete behavioural processes to facilitate the relationship between a company's knowledge base and the realization of radical innovation and offers a better understanding in this complex relationship.

The conceptual model



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1. Introduction

Over the past decade, the competitive environment has increased tremendously due to globalization. Because of the increased competition, companies are searching for strategies that will give them a sustainable competitive advantage. This advantageous desire forces companies to continuously innovate in terms of products and services (Popdiuk and Choo, 2006). A constant flow of break-through products and services resulting from radical innovation is desirable for companies to grow fast and maintain high margins (von Hippel, Thomke and Sonnack, 1999). Radical innovation involves significant leaps in technological development of products or services. Consequently, existing substitutes become obsolete (Leifer et al. 2000). In other words, radical innovation changes the competitive landscape and creates new market opportunities (Abernathy and Utterback, 1978). Therefore, it seems important to identify the drivers that are behind radical innovation.

To achieve innovation, a thoroughly planned system of knowledge management is required. Successful knowledge management enables the company to acquire valuable insights in the fields of marketing, administration and technology (Popdiuk and Choo, 2006). Many scholars have identified the knowledge-based view (KBV), which is described as the capability of a firm to control, conserve and create knowledge (Grant, 1996). According to Hill and Rothaermel (2003), a company's existing knowledge base defines the ability to assimilate new knowledge into radical innovation. However, the complex and strong relationship between knowledge creation and innovation seems to be infrequently examined (Popdiuk and Choo, 2006). Furthermore, the older KBV studies that have been conducted tend to focus on the relationship between knowledge and innovation performance in general (Bierly and Chakrabarti, 1996). However, research that has been conducted whether a company's knowledge base could be the unique ingredient for radical innovation, provides conflicting results (Zhou and Li, 2012).

For example, Chesbrough (2003) asserts that a broad knowledge base is beneficial to achieve radical innovation. The diversity of knowledge hold by the company enhances the assimilation of new information and identification of new market opportunities, resulting in radical innovation. However, Laursen and Salter (2006) warn that the broad knowledge base could be an obstacle to fully utilize the ideas created. They elaborate on this statement by giving three problems that companies with a broad

knowledge base face: there are too many ideas to manage or choose to implement (1), the ideas are coming at the wrong place at the wrong time (2), and the amount of ideas limits the company to give the required attention (3). In sum, the breadth of knowledge provides novel ideas, but lacks sufficient coordination and experience to fully execute the ideas into radical innovation.

On the other hand, Zahra and George (2012) claim that a deep knowledge base is required to achieve radical innovation. In fact, they argue that the expertise, which is associated with a deep knowledge base, is the resource to fully implement novel ideas. Yet, Leonard-Barton (1992) asserts that companies with a deep knowledge base tend to have rigid mental short-cuts in order to solve problems, preventing them of developing radical breakthroughs.

Zhou and Li (2012) address these inconsistencies by stating that knowledge acquisition and sharing determine whether a knowledge base affects radical innovation. However, literature shows that the phenomenon of knowledge acquisition and knowledge sharing is not that explicit. For example, Hill and Rothaermel (2003) claim that radical innovation could only be achieved by acquiring new knowledge or recombining new parts with existing knowledge within the company. While others argue that knowledge integration mechanisms are necessary to achieve radical innovation (Zander and Solvell, 2000). Therefore, this paper builds upon the research of Zhou and Li (2012) by investigating whether organizational processes result in radical innovation, while having a broad or deep knowledge base. Which leads to the following research question:

How does a company's knowledge base result in radical innovation?

In the remainder of this paper, multiple sub-questions will be developed in the literature review that will help to answer the research question in full.

A provided answer on the research question adds value to both literature and practical implications. First, findings on how a company's knowledge base result in radical innovation advances more insights about the complex relationship between knowledge management and product innovation. Conceptual work is required, yet empirical testing is necessary to prove validity and add value to the literature (Blumberg, Cooper and Schindler, 2011). This research is the first to empirically examine through which

concrete behavioural processes a company's existing knowledge base could result in radial innovation. Last, this research builds upon the findings of Schulze and Hoegl (2008) to see whether the four behavioural processes of Nonaka (1994) could lead to radical innovation rather than just novel idea generation. The conclusions drawn from this study provide practical implications for managers to serve as guidance to implement the correct knowledge integration or acquisition process, after assessing the knowledge resources of the companies.

The remainder of this paper is as follows; the core variables of this study will be explained in the next chapter, followed by theoretically derived and empirically testable hypotheses. After that, this work presents a detailed description of the context and the methodology. Finally, this study will conclude with the presentation of the findings and implications for both theory as practice and suggestion for further research.

2. Theoretical background

There is a lot of ambiguous interpretation in the usage of the constructs "radical innovation", "deep and broad knowledge bases" and "knowledge conversion modes" in the literature. Therefore, a proper explanation and definition of these constructs would be useful and are presented in this chapter. As introduced in the previous chapter, the main focus of this research is the relationship between a company's knowledge base and radical innovation. Furthermore, this study tries to investigate the effect of behavioural processes, namely socialization, combination, internalization and externalization, on knowledge management and radical innovation. In order to understand the relationships between the different variables, a better comprehension of the present knowledge available concerning the constructs is evidently valuable.

2.1 Radical innovation

Due to the intensified competitive environment that emerged in the 1990s as a result of globalization, it is essential for companies to achieve a sustainable competitive advantage (Popadiuk and Choo, 2006). In order to realize this competitive advantage, companies are required to be innovative; i.e. they have to constantly differentiate their products and services in order to compete (Hurmelinna-Laukkanen, 2011). In extant literature, innovation contains concepts such as "*novelty*, *commercialization* and/or *implementation"* (Popadiuk and Choo, 2006, p. 303). This means when an idea is not advanced into merchandise, a process or service, or has not been commercialized, it does not subsume as innovation (Popadiuk and Choo, 2006). To put it in other words, innovation is the implementation of ideas within a firm (Amabile, 1988). Thus, the innovation process consists of both an ideation phase and an implementation phase (Zhou and Li, 2012).

Radical innovation differs from other types of innovation on several aspects. In order to avoid confusion or overlap of the different concepts, it would be wise to touch upon disruptive, discontinuous and incremental innovation. Christensen and Overdorf (2006) remark disruptive innovation as a product or service with a lower performance offered at a much lower price. The product has value for a small number of customers who do not require high technological performance. Over time, the disruptive product could improve as much that it deposes the incumbent (Christensen and Overdorf, 2006). Discontinuous innovation is described as a new-to-the-world product or service, with a design or

operation for which no product has previously existed (Popadiuk and Choo, 2006). Finally, incremental innovation is defined as small changes or adjustments to existing products or services with the goal to improve them (von Stamm, 2003).

Leifer et al. (2000) define radical innovation as an innovation that contains one or more of the following characteristics: a product or service that offers a completely novel series of performance features (1), a product or service that improves in current performance features with a magnitude of 5 times or greater (2), a product or service that has a reduction in cost of 30% or greater (3). The improvement in product features could be measured in terms of speed, efficiency, energy consumption, etc. In sum, radical innovation includes the commercialization of products and services that imply considerable leaps in technological development. As a result, the new product or service possesses entirely new properties or grand improvements in performance or cost in comparison to existing substitutes (Leifer et al., 2000). In other words, radical innovation strives for revolutionary changes in technology that are significantly different from existing practices (Ahuja and Lampert, 2001).

Radical innovation seems to be of great importance for companies for several reasons. First, radical innovation has the power to eliminate incumbent firms (Foster, 1986). When a radical innovation assures improved performance for a lower cost than the products of an incumbent company, customers do not hesitate to switch. As a result, huge amounts of investments made in the past become fruitless as the skills do not apply to the new generation of products anymore (Chandy and Tellis, 1998). Second, radical innovation equals competitive advantage, which results in positive, large and long-lasting profits (Geroski, Machin and van Reenen, 1993). Last, the rate of radical innovation seems to be increasing in frequency (Foster, 1986, as cited in Chandy and Tellis, 1996). Therefore, companies are urged to be innovative in order to stay competitive (Chandy and Tellis, 1998).

However, Pedersen and Dalum (2004) elaborate on the fact that radical innovation also implicates a certain degree of risk for both organizations as well as the industry, as it eliminates previous investments in skills, knowledge, design, procedures or equipment. Mason and Milne (1994) use the term sales cannibalization, which means the loss of sales of a company's present products as a result of its newly introduced product. Nonetheless, Chandy and Tellis (1998) argue that the willingness to cannibalize is

a desirable characteristic of a firm in order to achieve radical innovation. In fact, Schumpeter (1942, as cited in Chandy and tellis, 1998) mentions the phenomenon of 'creative destruction' (p. 475) where innovation sweeps away the market positions of companies dedicated to old technology.

2.2 A company's knowledge base

Knowledge is defined in business research as "information that is relevant, actionable and based at least partially on experience" (Leonard and Sensiper, 1998, p. 113). It is a collection of subjective information and tacit elements derived from experience (Leonard and Sensiper, 1998). Polanyi (2012) assumes that knowledge exists on a scale of two extremes. At one side, knowledge is completely tacit, which means unconscious knowledge that is based on rituals, inborn usages, implied values and preconceptions. On the other end, knowledge is completely explicit, structured, codified and accessible to other people. Naturally, most knowledge holds within those extremes.

Leonard and Sensiper (1998) underline the importance of knowledge in the innovation process, as the process of developing new products and services is more complicated than ever. Merging knowledge of individuals with different backgrounds, disciplines and personal skill-based perspectives could overcome this increased complexity (Leonard and Sensiper, 1998). Moreover, Grant (1996) states that innovation is impossible without a company's ability to control, uphold and create knowledge. Knowledge within a company includes intuition, models, experiences, values, facts, ideas, opinions, contextual information and expert insight (Mitri, 2003). Hill and Rothaermel (2003) argue that a company's knowledge base is an unique ingredient in order to achieve radical innovation.

A knowledge base represents both structure and content of the knowledge a company holds (Zhou and Li, 2012). The breadth of a company's knowledge base is the level of which it includes distinct and various knowledge domains (Bierly and Chakrabarti, 1996). The breadth refers to a horizontal dimensional structure with heterogeneous content through excessive knowledge sharing (De Luca and Atuahene-Gima, 2007). A company with broad knowledge possesses diversified knowledge of customer portfolios, market segments and technological background (Zhou and Li, 2012). A broad knowledge base contains various, stacked observations and signals that facilitate the comprehension of novel

information and potential changes. As a result, the company is able to spot distant technological or market opportunities to achieve radical innovation (Chesbrough, 2003).

The depth of a company's knowledge base explains the sophistication and complexity of knowledge in essential areas (Bierly and Chakrabatri, 1996). The depth refers to the vertical dimensional structure with a complex, exclusive and within-field knowledge content (De Luca and Atuahene-Gima, 2007). Hence, a deep knowledge base is about the thoroughness of knowledge and the technical expertise in specialized fields (Zhou and Li, 2012). Zahra and George (2002) assert that the depth of a knowledge base is essential to achieve radical innovation in a specific industrial field, as it facilitates the implementation of significant new ideas.

An example which explains the breadth and depth of a company's knowledge base concretely could be given through the research methodology of Zhang and Baden-Fuller (2010). They define companies with broad knowledge as those that have patents diffused over different, multiple technological classes. In contrast, companies with deep knowledge are defined as those that had a relatively large share of patents within one class: focusing their expertise in one technological area. Moreover, a company with broad knowledge tends to have diversified customer portfolio and targets several market segments, such as a consultancy agency. Meanwhile, a company with deep knowledge has thorough knowledge and experience within their own industry and possesses a deep understanding about the needs of the current customers of their key market segment (Zhou and Li, 2012). A possible example of this is a manufacturer in nail polishes, such as Herôme.

Zhou and Li (2012) provide valuable insights for this study as they showed that knowledge sharing and acquisition are enablers for radical innovation under different knowledge bases. However, there are still a lot of controversial views of scholars when and whether a broad or deep knowledge base is the unique ingredient to achieve radical innovation. Furthermore, there is limited amount of research conducted whether organizational processes are possible mediators for companies with different knowledge bases and radical innovation. Therefore, the first two sub-questions of this study are as followed:

Sub-question 1: Through which organizational processes does a company's deep knowledge base result in radical innovation?

Sub-question 2: Through which organizational processes does a company's broad knowledge base result in radical innovation?

2.3 Knowledge conversion modes

As mentioned before, the management, preservation and creation of knowledge seems to be the unique ingredient to foster radical innovation. Nonaka and Takeushi (1995) claim that the knowledge creation of a company occurs through the alteration and communication between its tacit and explicit knowledge. The alteration between these two types of knowledge is considered a social process and not restricted to one individual (Popadiuk and Choo, 2006). Nonaka and Takeushi (1995) identified four knowledge conversion modes, see Table 1 below.

Conversion mode	**From**	**To**
Socialization	Tacit knowledge	Tacit Knowledge
Internalization	Explicit knowledge	Tacit Knowledge
Externalization	Tacit knowledge	Explicit knowledge
Combination	Explicit knowledge	Explicit knowledge

Table 1 The Four Knowledge Conversion Modes

Nonaka and Takeushi (2001) argue that knowledge is subjective, and it is only given meaning to by how one is using it. In other words, knowledge is the construction of reality rather than an objective and universal belief. The above knowledge conversion modes are seen as enablers to transfer knowledge, which could take place on a physical, intellectual or virtual level or all three (Popadiuk and Choo, 2006).

Nonaka (1994) built theoretical work, whereas Schulze and Hoegl (2006 and 2008) conducted empirical work and developed and validated measurement items with regards of these four knowledge transfer modes. In order to fully understand how the four knowledge conversion modes work, a brief description of the main features of each mode is given below.

Socialization is a knowledge conversion mode where new tacit knowledge is created through the communication of tacit knowledge in an informal way (Nonaka and Takeushi, 1995). These informal meetings take place in different settings, e.g. through spending time together, shared experiences, working in a similar environment and in meetings outside the working place between individuals of a company (Schulze and Hoegl, 2008).

Combination is described as a process where explicit knowledge is shared as explicit knowledge. Through this process, one sees links between previously disconnected knowledge areas (Schulze and Hoegl, 2008). Combination involves gathering, combining and distributing knowledge between individuals of a company through presentations and meetings (Nonaka and Takueshi, 1995).

Externalization is a knowledge conversion mode where tacit knowledge is codified in explicit knowledge in a formal setting, e.g. expert interviews or communicated lessons learned in previous activities (Schulze and Hoegl, 2008). Knowledge is shared through analogies, concepts, forecasts, graphs, images or prototypes. By using these tools of communication, discrepancies could emerge, resulting in an interesting discussion and reflection between persons (Nonaka and Takueshi, 1995).

Internalization is referred to as the process where individuals apply explicit knowledge, and as a result digest, incorporate and adapt it into personal tacit knowledge, i.e. learning by doing (Schulze and Hoegl, 2008). Activities mentioned in order to achieve internalization are trainings, simulations and experiments and the fostering of cross-functional development teams (Nonaka and Takeushi, 1995).

Nonaka and Takeuchi (1995) identified the four knowledge transfer modes to establish a link between knowledge creation and idea generation in the innovation process. Lee and Choi (2003) found that these knowledge transfer modes are positively related with organizational creativity which consequently leads to organizational performance. However, Schulze and Hoegl (2008) found contradicting results showing that only internalization and socialization have positive effect on the generation of novel product ideas, while externalization and combination have a negative effect. Yet, the innovation process consists of both an idea generation phase and an implementation phase. Besides these two empirically tested studies, no work has been conducted to test the possible effect that the four modes have on the innovation

process as a whole. Additionally, as mentioned above, a company's existing knowledge base has an influence on the way knowledge management should be conducted to foster radical innovation, rather than incremental ones. It is important to stress that the core of this study is not to focus on the transfer of tacit to explicit knowledge or vice versa, but as behavioural processes to acquire or share knowledge within a company. Therefore, the knowledge transfer modes will be addressed as the behavioural processes of Nonaka (1994) in the remainder of this paper. The contradicting results and research gap provide insights to develop the following sub-question:

Sub-question 3: Are the four behavioural processes potential enablers to achieve radical innovation when possessing different knowledge bases?

Concluding this chapter, it becomes clear that several constructs are the key focus of this thesis. In summary, radical innovation differs from other sorts of innovation and is considered leaps in technological advancement that create new product characteristics or big improvements in cost reduction and performance. The radical innovation process consists of an idea generation phase and an implementation phase. The knowledge base of a company refers to structure and content of the knowledge a company possesses. Broad knowledge holds heterogeneous content that is structured through horizontal lines, whereas deep knowledge includes profound and exclusive know-how in specific areas and is spread vertically. The four behavioural processes discussed are the knowledge transfer modes of Nonaka (1994). First, socialization describes the process where tacit knowledge is shared within an informal setting with individuals across the company. Second, combination is referred to as the behavioural process where new links are established of old knowledge to spark new insights. Third, externalization is the search of new perspectives regarding customers' needs and technology. This happens by interviewing experts in that field in order to combine the new insights with existing knowledge of the company. Final, internalization means that individuals learn by doing, such as performing experiments.

3. Hypotheses

Following from this paper's research question and the sub-questions phrased in the literature chapter, this section discusses the theoretical relationships between the main variables of the study.

Through which organizational processes does a company's deep knowledge base result in radical innovation?

This work argues that the depth of a company's knowledge base could lead to radical innovation through externalization and internalization. In fact, Zahra and George (2002) suppose that deep knowledge is critical to achieve radical innovation. The profound experience and know-how about current technologies and markets accomplishes the realization of important novel ideas. However, although companies come up with favourable product ideas, they often lack the experience to solve difficult problems they encounter in the implementation phase (Laursen and Salter, 2006). In fact, Leonard-Barton (1992) argues that the depth of a company's knowledge base is possibly a constraint. He asserts that deep knowledge results in observational slowness, bounding a company to current market segments and technologies for incremental rather than radical innovation.

Therefore, Zhou and Li (2012) propose that these possible constraints could be overcome through knowledge acquisition in order to achieve radical innovation. Indeed, companies with deep knowledge that focus on internal knowledge sharing only achieve a deeper know-how on an individual level. Yet, they fail to expand the scope of information to seek for new opportunities, technologies and markets (Kale, Dyer and Singh, 2002). Furthermore, Zhou and Li (2012) argue that when a company integrates new information about potential markets with the existing deep understanding of their current targets, it is able to detect future market trends and invest accordingly.

Furthermore, besides the fact that a company with deep knowledge tends to stay in the same market segments, it is also likely to stick with current, familiar, specialized practices (Christensen, 2006). Consequently, the company becomes more efficient in existing routines but also creates the above mentioned observational slowness to explore potential opportunities (Tripsas and Gavetti, 2000). Leonard-Barton (1992) underlines this statement by explaining that these familiar routines create

cognitive maps that are used to solve problems. As a result, these maps continuously lead to similar solutions. Thus, incremental innovation is achieved instead of radical innovation.

In order to overcome this slowness, companies need to engage in conversations with experts of different market domains, technologies and customer needs. Looking for insights outside the boundaries of the company expands the diversity of knowledge domains. This could potentially modify the observational structure of the company in order to discover competence defectiveness and revive the current organizational processes and routines. In this way, the company creates and implements novel ideas successfully (Zhou and Li, 2012). In fact, exposure to novel knowledge that is not embedded in the deep know-how of the company creates the opportunity for new modes of reasoning and causes variation in cause-and-effect understanding. Consequently, the problem-solving arsenal of a company becomes more heterogeneous, hence more broad. Furthermore, the novel knowledge acquired could advance new insights which could provide the base of radical innovation (Ahuja and Lampert, 2001).

Externalization is described as the behavioural process of codifying knowledge in a formal setting, such as expert interviews. Consequently, this newly gained information is shared through analogies, concepts, forecasts, images, graphs etcetera. A company can overcome grounded routines through knowledge acquisition about new, emerging technologies and markets through expert interviews. In this way, a company with deep knowledge will achieve radical rather than incremental innovation. Externalization enables a company with deep knowledge to explore potential opportunities, broaden the ways of reasoning and gain a revived look at cause-and-effect understanding, in order to solve problems in the radical innovation process. Thus, this leads to the following hypothesis:

Hypothesis 1: Externalization positively mediates the relationship between a company's deep knowledge base and radical innovation.

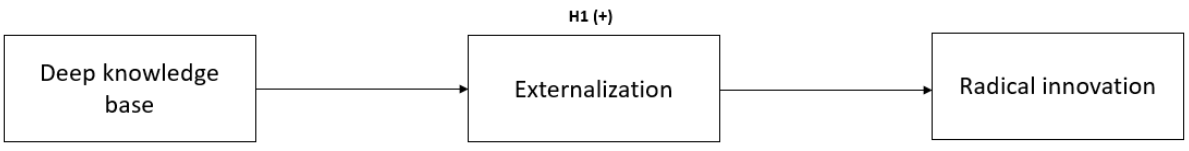

Figure 1 Graphic Display Of Hypothesis 1

Furthermore, internalization is described as the behaviour where new tacit knowledge is acquired through extensive experience and experimentation (Schulze and Hoegl, 2008). Through this process, individuals gain personalized knowledge about opportunities and limitations of technologies which goes beyond what they might have read or heard about (Dougherty, 1992). Schulze and Hoegl (2008) argue that through internalization, individuals create an image of the product in use. As a result, they develop a deep sense of problems that consumers are facing when it comes to technologies and manufacturing processes.

Companies with deep knowledge need to avoid the familiarity trap and break through deep-rooted routines to achieve radical innovation. Therefore, it would be logical to assume that internalization is a process that could help overcome the cognitive slowness mentioned before. The depth of its knowledge causes the company to have rigid mental short-cuts in order to solve problems, preventing them from developing radical breakthroughs (Leonard-Barton, 1992). Fiol and Lyles (1985, as cited in Ahuja and Lampert, 2001) underline the importance of experimentation in order to overcome these mental short-cuts, as it provides new insights to address problems.

To follow a similar note of externalization; internalization provides a company with deep knowledge the opportunity to gain new knowledge to enhance the heterogeneity in the problem-solving abilities, create new perspectives of potential new markets and (use of) technologies. Furthermore, it enables them to question current cognitive short-cuts which consequently could lead to generating new, break-through solutions. Therefore, this work proposes the following hypothesis:

Hypothesis 2: Internalization positively mediates the relationship between a company's deep knowledge base and radical innovation.

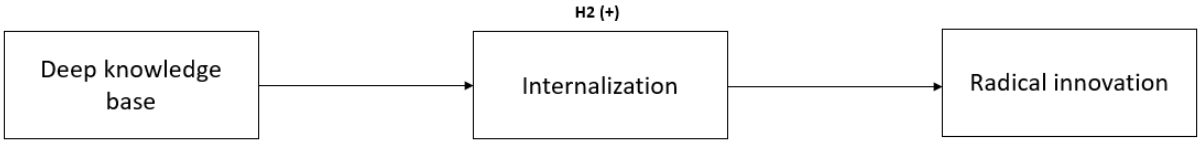

Figure 2 Graphic Display Of Hypothesis 2

Through which organizational processes does a company's broad knowledge base result in radical innovation?

This work also argues that the breadth of a company's knowledge base could lead to radical innovation through socialization and combination. Similar with the depth of a knowledge base, there are conflicting theories whether or not broad knowledge is a profound base to achieve radical innovation (Zhou and Li, 2012). For example, Taylor and Greve (2006) believe that companies with a broad knowledge base have a higher chance to develop breakthrough ideas through new combinations of knowledge parts than companies with a deep knowledge base. Chesbrough (2003) agrees by stating that radical innovation is achieved by companies that contain a broad knowledge base as they are able to detect changes and opportunities in both technological as well as market components through various gathered observations and indications. However, Laursen and Salter (2006) warn that broad knowledge could be an obstacle to fully utilize the ideas created. Indeed, they believe that these ideas will lead to incremental innovation, because the breadth of the knowledge prevents companies with sufficient coordination and experience to fully execute the ideas into radical innovation. In conclusion, the breadth of a company's knowledge does not seem to provide the sufficient base to achieve radical innovation. Verona (1999) indicates that a company has to put the appropriate knowledge integration mechanisms in place to catch, interpret and proliferate its knowledge resources.

Zhou and Li (2012) investigated the proposition of Verona (1999) and found that a company with broad knowledge indeed benefits from knowledge sharing in order to achieve radical innovation. As stated before, a company with a broad knowledge base has gathered know-how across various branches of knowledge and divergent market domains through its comprehensive knowledge exploration (Chandy and Tellis, 1998). Therefore, acquiring additional information would only have a marginal effect: chances are that the new information overlaps with existing knowledge. Consequently, knowledge acquisition would only lead to refinement of the current knowledge base, rather than creating breakthrough ideas (Zhou and Li, 2012).

However, once knowledge is shared within a company with a broad knowledge base, combinations of different insights could spark new, unseen patterns (Zahra and George, 2002). As a result, the

heterogeneous knowledge of the company is integrated to achieve an efficient idea phase of radical innovation. Furthermore, acquiring new knowledge could potentially lead to an information overload. The cognitive attention of a company is confined, and working on too many projects could lead to failure of any individual project (Laursen and Salter, 2006). Moreover, managing a broad range of knowledge makes it difficult to take advantage of heterogeneous know-how. In order to achieve radical innovation, an adequate understanding and complete application of the acquired knowledge is necessary; otherwise incremental innovation is the obvious result (Katz and Du Preez, 2008).

Therefore, it seems logical to assume that a company with broad knowledge benefits more from knowledge sharing within the firm. This way, the company does not get overloaded by information that does not add value during the radical innovation process. Moreover, combining the different knowledge domains across various disciplines and departments could spark new insights.

Socialization is described as the behavioural process where tacit knowledge is transferred during informal settings across employees of a company, especially across different departments. In fact, Schulze and Hoegl (2008) stress the importance that innovation is a collaboration, not an one-person job. Even more so, it requires stimulation of a necessary variation of sparks that allows a focus on actionable next steps (Leonard and Sensiper, 1998). Through socialization, individuals with different backgrounds work towards a common goal and bring their own experience and cognitive resources regarding both the problem as well as the solution to the table (Schulze and Hoegl, 2008). An extra advantage of socialization is the casual setting where trust and informal networking are keys to avoid disagreement over strongly held preferences and beliefs (Leonard and Sensiper, 1998).

Thus, when a company with a broad knowledge base does not seem to benefit from knowledge acquisition, socialization could potentially be the key to achieve radical innovation. The different backgrounds of individuals could potentially create new insights out of old knowledge to enhance the novelty of product ideas. Furthermore, it helps a company focus its cognitive attention on just a couple potentially successful products, rather than working on many ideas to achieve successful implementation of the product. The informal interaction of socialization fosters trust and tranquillity in order to avoid conflicts.

Thus, this leads to the following hypothesis:

Hypothesis 3: Socialization positively mediates the relationship between a company's broad knowledge base and radical innovation

Figure 3 Graphic Display Of Hypothesis 3

Moreover, combination is described as the behavioural process where existing knowledge is systematized and shared throughout the company through presentations, documents, telephone conversations, meetings or communication networks (Nonaka and Takeushi, 1995). Some scholars argue that combination has a negative effect on novel product ideas (Schulze and Hoegl, 2008). However, this work proposes that it would have a positive effect on radical innovation when a company has a broad knowledge base. Henderson and Clark (1990) argue that the combination of existing knowledge only leads to incremental innovation, but is insufficient to create breakthrough innovation. However, research shows that the behavioural process of combining existing knowledge leads to creative thinking (Kanter, 1988). This reinforces the argument given before, that it results in the connection and integration of the broad knowledge across various disciplines. This recombination of knowledge generates undiscovered patterns to generate breakthrough innovations (Zahra and George, 2012).

Furthermore, the formal and documented aspect of combination provides easy access at all times to all departments of a company (Dahl and Moreau, 2002). The knowledge is contained within formal documentation, which prohibits the loss of valuable information when employees leave the company. Furthermore, the knowledge is distributed actively within the company through combination. As a result, the interaction among members of the broad knowledge base is increased and potentially provide insights in the know-how of others on one's own work to achieve radical innovation (Zhou and Li, 2012). Based on the arguments mentioned above, the following hypothesis can be formulated:

Hypothesis 4: Combination positively mediates the relationship between a company's broad knowledge base and radical innovation

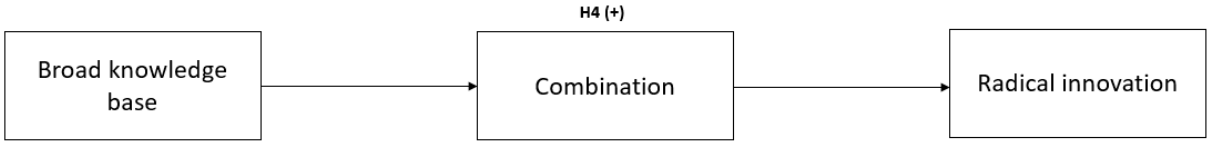

Figure 4 Graphic Display Of Hypothesis 4

Are the four behavioural processes potential enablers to achieve radical innovation when possessing different knowledge bases?

In summary, this work argues that a company with a deep knowledge base achieves radical innovation through externalization and internalization. Moreover, a company with a broad knowledge base may achieve radical innovation through combination and socialization. Figure 5 summarizes the above hypotheses and displays the conceptual model of this thesis. The following chapter continues with the methodology used to test the developed hypotheses.

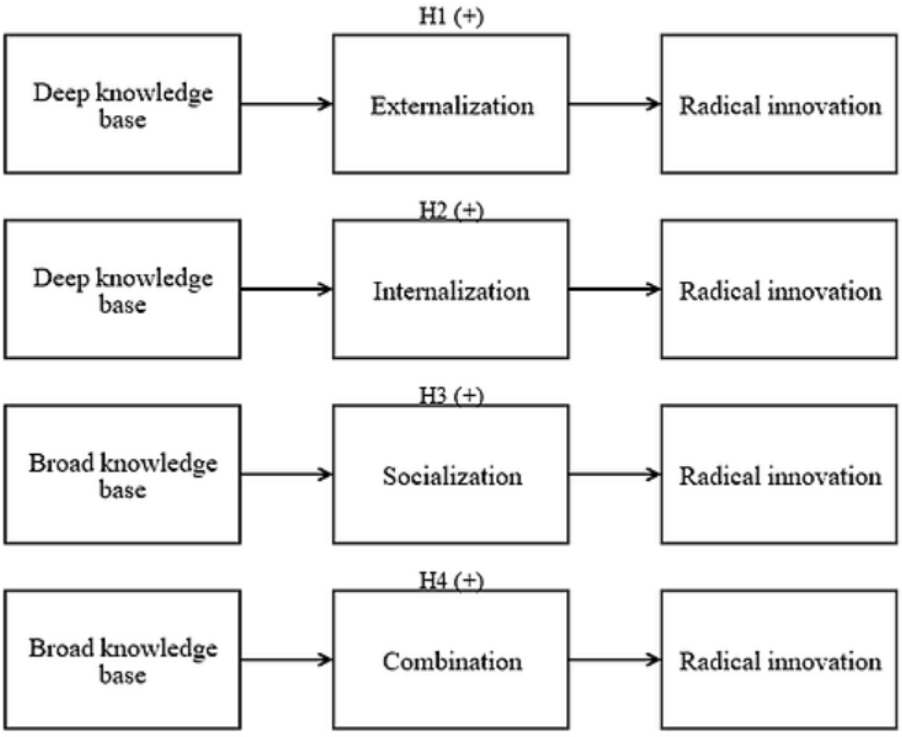

Figure 5 The Conceptual Model

4. Research methodology

4.1 Context selection

The relationships presented in the hypotheses will be investigated in the context of companies that operate within the Life Sciences and Healthy industry (LSH) in the Netherlands. The LSH industry include all companies operating in the production, research and/or development of medical or pharmaceutical products, which have their main office located in the Netherlands. The industry includes several sub-industries, namely: Manufacturing of pharmaceutical raw materials (SBI code 21.1), manufacturing of pharmaceutical products (SBI code 21.2), biotechnological research and development in the field of medical products, pharmaceutical processes and food (SBI code 72.11.2), and manufacturing of radiation appliances and electro-medical and electrotherapeutical appliances (SBI code 26.6). The SBI codes are specified by the Dutch Central Bureau of Statistics (CBS, 2016a). In similar studies, authors included different industries as a control variable in the analysis as differences in these industries may affect the realization on radical innovation (Schulze and Hoegl, 2008; Zhou and Li, 2012). However, this study focuses only Dutch companies in one concrete, innovative industry, eliminating the concern of endogeneity. Therefore, (sub)-industry is not included as a control variable in the analysis.

There are several reasons why the context was limited to the Netherlands. First, the geographical location adds to the feasibility for the author. Second, Eurostat (2015) conducted a Community Innovation Survey. The results show that the Netherlands are only 3,2% under the average (48.9%) of the European top 15 regarding the percentage of companies that are actively innovating. Furthermore, innovation is one of the 12 measurements used to establish the Global Competitive Index. In 2015-2016, the Netherlands ranked 8th on this index, whereas it was only 15th in 2006-2007 (World Economic Forum, 2016). Moreover, the European Commission (2015) showed on their European Innovation Scoreboard that the Netherlands grew from *innovation follower* to an *innovation leader* in 2015. Additionally, the CBS observed that the R&D-expenditure of businesses in the Netherlands is increasing every year (CBS, 2014a). All of the above could indicate that the percentages of radical innovation

increased in the Netherlands over the last two years, improving our position in the Global Innovation Index and European Innovation Scoreboard.

Next to the geographical location, there are several reasons why the LSH industry was selected. According to CBS (2016b), the LSH-industry is at top of its game. In fact, of all the big industrial sectors in the Netherlands, the pharmaceutical manufacturing industry grew the strongest in the last two years. In fact, the production of the pharmaceutical industry was in 2015 19% higher than two years before (see figure 6). The pharmaceutical manufacturing sector takes up 5,8% of amount in the daily production in the Netherlands.

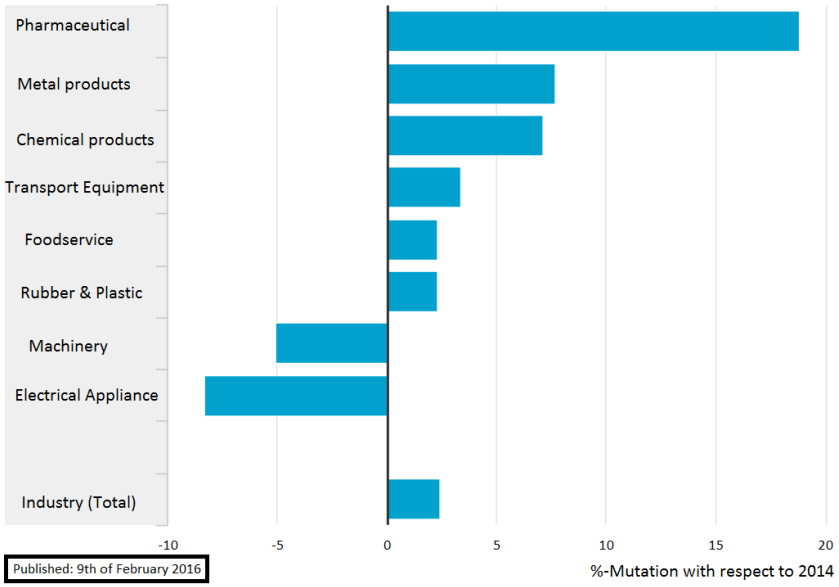

Figure 6: Growth manufacturing industries in 2015 with respect to 2014 **Source: CBS**

Furthermore, an annual survey conducted among LSH CEOs in 2015 shows that most companies have been investing heavily in digital technologies. Results of the survey indicate that these investments create opportunities for the pharmaceutical companies to innovate (PWC, 2015). Additionally, the European Federation of Pharmaceutical Industries and Associations (EFPIA) emphasizes that innovation in this industry contributes tremendously to the well-being and life expectancy of European citizens. The current numbers show a reduction in dead by HIV/AIDS and some forms of cancer thanks to recent innovations. Next to the health benefits, innovation and medical progression in research also

provides an important contribution to the European economy. All this underlines the importance of the innovative structure of the LSH-industry (EFPIA, 2016).

Zooming in on the LFS-industry in the Netherlands, CBS (2014b) listed it as an innovative top-sector. Expenditure on R&D in this sector contributes 12% of the total expenditure in the Netherlands. This percentage is relatively large in comparison to the economic scope of this sector. Additionally, an above average percentage of the companies are engaged in innovation in the sector, namely 60% in 2012. In fact, the average of all companies engaged in innovation is 38% and 52% in the top sectors in the Netherlands (see figure 7).

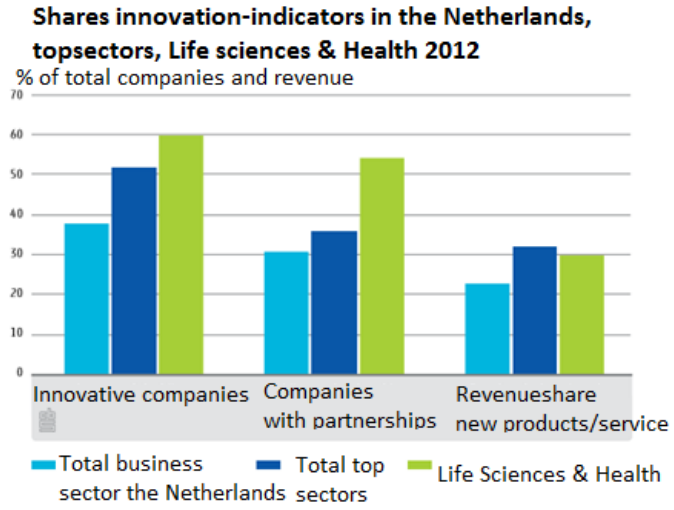

Figure 7: Percentage of LSH-companies that innovate with respect to other Top Sectors in the Netherlands **Source: CBS**

Noteworthy, CBS (2014b) also states that the sector has the highest percentage of highly-educated personnel in the sector (61%). These highly-educated personnel are also referred to as knowledge workers. This is an important characteristic of the LSH-industry to mention, as knowledge bases are an important cornerstone of this study.

The Life Science and Health industry includes companies that focus on the manufacturing and research of pharmaceutical and medical products. As stated before, service companies are not the focus of this study. In fact, innovations developed in the manufacturing sector include sequential technological components, whereas innovations in the service sector do not (Damanpour, Walker and Avellaneda,

2009). As the process of innovation is significantly different in service companies, these are excluded of the study.

4.2 Data Collection

In order to fully answer the main research question of this study, primary data will be collected through self-administered surveys. These surveys will be sent out through electronic mail. Reasons for this are versatile. First, data gathering through surveys is more cost-effective and efficient than observation (Blumberg, Cooper and Schindler, 2011). Second, it provides the author the opportunity to expand the geographic area and contact individuals who would otherwise be inaccessible respondents. Third, the information sought regarding the mediating variables are perceptual, so a communication approach is the most suited option. The survey is developed in both Dutch as well as English. Although the survey will be distributed to companies with the main office located in the Netherlands, it is assumable that English-speaking employees are also working in these locations. In order to reduce translation bias, the survey will be translated following a back-translation approach by consulting a bilingual friend of the author (Zhou and Li, 2012). Through this approach, it is possible to examine if the Dutch survey captures the meaning of questions similar to the English version given in the appendix (See appendix A).

However, this data collection method comes with certain challenges. The quality and quantity of information is dependent on the ability and willingness for participants to cooperate. Therefore, it is the responsibility of the author to ensure motivation and willingness to participate. In order to accomplish this, an introduction will be included in the measurement instrument, explaining the value and objective of the study. Furthermore, a small incentive (3 available ‘staatsloten’) will be allotted among the respondents to increase the motivation to participate. Also, Blumberg, Cooper and Schindler (2012) emphasize that stressing that the participant’s help is needed for the study has a significant impact in response rates. Furthermore, the questions asked and the sequence of the survey should provoke interest and increase motivation. So, the questions contribute to hard data but also contribute to the motivation level of the participant. Additionally, non-response error could be reduced by introducing follow-ups or reminders, and provide a preliminary notification when possible. Therefore, two reminders were sent to the potential respondents to fill in the questionnaire. A key informant is selected for each organization

which is believed to have sufficient knowledge about the topic, namely someone who operates in R&D or in the product-development department or is CEO of the company.

The unit of analysis for this study are companies. In order to increase comparability, this study will focus on the realization of radical innovation of physical products only. Reason for this is that behavioural processes such as internalization would be conducted significantly different concerning services than it does with products (Schulze and Hoegl, 2008). Similar studies in the field of radical innovation tend to focus on the idea or implementation phase of radical innovation regarding a newly released product (Schulze and Hoegl, 2008; Zhou and Li, 2012). This study focuses on the company as a whole when it comes to the four behavioural processes. This is because this study tries to investigate if the common use of this behavioural processes has a positive influence for different knowledge bases on radical innovation. This research draws from data from one respondent per company, working in R&D, Product Development or is a CEO, due to several reasons. First of all, one-respondent surveys increase feasibility and decrease the chances of non-response error. As stated before, non-response error is a big challenge in self-administered surveys when participants do not see the value in participating or do not have the time. This risk is increased when two (or more) people within one company are asked to answer the survey, as it double the chances of not seeing the value or not having the time. Therefore, one-respondent answers are chosen. Second, due to the moderate complexity of the questions and the targeted job function of the respondents, it is reasonable to assume that one respondent has the significant knowledge of the subject to answer the survey fully and accurately (De Luca and Atuahene-Gima, 2007). Last, multiple research shows that data retrieved from one-respondent also provides significant results (Zhou et al., 2005; Zhou, 2006).

The Dutch Chamber of Commerce provided the sample list of 546 companies operating in the Life Science and Health sector. The list includes companies willing to share their contact information with the Dutch Chamber of Commerce, have their main location based in the Netherlands and are economically active. After removing duplicates and irretrievable electronic mail-addresses, 425 companies remained, out of the total of 1144 businesses active in the industry. This means that there are 598 companies that are economically active in the industry, but are not willing to share their contact

information. As the whole population list is not available, this study uses a non-probability sampling approach. Potential bias that derives from this sampling method, will be discussed in the results chapter.

In the end, 81 surveys were successfully returned out of the 425 initial surveys sent, resulting in a response rate of 17,88%. However, two surveys were excluded in the final sample as some data was missing. The final sample used in the analysis consists of 79 observations. There are numerous reasons which could clarify the relatively low response rate. Blumberg, Cooper and Schindler (2011) remark that non-response error is the primary weakness in self-administered and web-based surveys. They identified several causes for non-response in this communication approach, for example: the questionnaire is too long or complex, participants do not see the added value, have no interest in the topic or feel that the data requested is too intrusive or sensitive. However, Blumberg, Cooper and Schindler (2011) also note that high response is a logical consequence when the topic is interesting and when the respondents are highly educated. Even the location could influence response rate: Europe tends to receive higher responses than the United States. There were several techniques used in order to achieve the highest response rate possible: an incentive was allotted among the participants that fully completed the questionnaire, an industry was chosen that has a relatively high proportion of highly educated people and it has been ensured that the participant had sufficient knowledge and information to correctly and fully answer the questions asked. Moreover, two reminder e-mails were sent.

4.3 Measures

Measurement are used which are available in the literature. Developed and tested measurement items improve the study's reliability and validity (Blumberg, Cooper and Schindler, 2011). The items are rated on a seven-point Likert scale (1 = 'strongly disagree,' 7= 'strongly agree'). The Likert scale is used the most in the category of rating scales in literature. One of the biggest advantages of the Likert scale is that it counteracts central tendency error. By adding more points on the scale, participants will be less reluctant to give extreme answers (Blumberg, Cooper and Schindler, 2011). A complete overview of all measurement items could be found in appendix A.

4.3.1 Dependent variable – radical innovation

The dependent variable in this study is radical innovation. This variable has been empirically tested through a survey approach before. Therefore, a validated composite measurement is already available in the literature. The measure used in this study of radical innovation is a 6-item composite measurement (Chronach's α = .84) adapted by Zhou and Li (2012). As mentioned in the literature review, radical innovation is defined by Leifer et al. (2000) as: a product that reduces costs with 30% or more, has improved performance features of a magnitude of 5 times or greater or contains totally new performance features. Indeed, this measurement item which is included in the survey assesses the degree of technological development, the introduction of totally new products and monetary performance concerning radical innovation (Zhou and Li, 2012).

4.3.2 Independent variables – knowledge bases

The breadth of the knowledge base

Although knowledge bases are rather difficult constructs to grasp, multiple scholars have examined both the breadth as well as the depth of knowledge base empirically (Bierly and Chakrabarti, 1996; Moorman and Miner, 1997). A 3-item measurement of the breadth of a knowledge base is included (Cronbach's α = .80), adopted from Zhou and Li (2012). Following the literature review, the measurement indicates the variety of the company's knowledge about the market, customer portfolio's and technological advancement (Zhou and Li, 2012).

The depth of the knowledge base

On a similar note, the 7-item composite measurement of Zhou and Li (2012) is included, capturing the knowledge breadth of a company (Cronbach's α = .85). This composite measurement reflects the thoroughness of the company's knowledge and its technical expertise in specialized fields.

4.3.3 Mediating variables – behavioural processes

In the literature review, four different behavioural processes are identified to transfer and share knowledge within a company. These behavioural processes are measured by items developed and validated by Schulze and Hoegl (2006).

The extent of internalization

Internalization is described as the process where individuals apply explicit knowledge, and as a result digest, incorporate and adapt it into personal owned tacit knowledge. This process is captured by the 4-item composite measurement of Schulze and Hoegl (2006). This measurement reflects the level of individual development of tacit knowledge through experiments within a company (Cronbach's $\alpha = .87$).

The extent of externalization

Externalization refers to the acquisition and encoding of tacit knowledge through expert interviews. The behavioural process of externalization (Cronbach's $\alpha = .86$) within a company is measured by a 4-item composite measurement (Schulze and Hoegl, 2006). These measurement items refer to the formal process of codifying newly gained information through interviews with experts into detailed descriptions.

The extent of combination

Combination consists of the foundation that knowledge is distributed within a company. By doing this, relationships of disconnected knowledge fields are revealed. The 4-item composite measurement of combination (Cronbach's $\alpha = .93$) that is included in the survey reflects the level of methodical gathering and processing of existing knowledge from various sources (Schulze and Hoegl, 2006). However, the scale is adapted to the research method of this study. The measurement items survey the process on the organization as a whole, rather than focusing on combination as a process which applies to a specific project (Schulze and Hoegl, 2008).

The extent of socialization

Socialization is the process where tacit knowledge regarding product ideas, suggestions and solutions is shared in an informal environment. A 4-item composite measurement (Cronbach's $\alpha = .88$) is included, assessing the level of informal interaction and exchanges between individuals regarding the innovation process (Schulze and Hoegl, 2006).

4.3.4 Control variables

Whilst not the focus of investigation of this study, multiple other variables have been included as they potentially affect radical innovation. Although the list is infinite, the ones mentioned below are included in order to decrease bias and gain insights on alternative explanations (Blumberg, Cooper and Schindler, 2012). First, **competition intensity** is included as a control variable. Multiple scholars identified the relationship between competition and innovation. However, there are contradicting results under different circumstances. Aghion and Griffith (2008) elaborate on the fact that increased competition could foster growth potential through imitation and adoption of technologies. However, they also emphasize that big innovators such as Microsoft are discouraged by competition as the expected returns from innovations are as low as ever. Although there are mixed results of the effect of competition on innovation, it is evident that there is a potential effect on the innovation performances of a company. Therefore, it is controlled for in this analysis. In order to measure the competition intensity within the industry, an adapted 4-item composite measurement (Cronbach's $\alpha = .38$) is included, developed by Jaworksi and Kholi (1993). However, it is evident that this Chronbach's alpha does not meet the minimum required value .70, set by Pallant (2010). In fact, the Cronbach's alpha indicates de internal consistency of the items that make up the composite measurement whether they all measure the same underlying variable (Pallant, 2010). This means that a high value of the α-coefficient indicates that the items in the underlying concept have shared covariance and measure the same thing. The statistical analysis shows that the removal of two items in this concept would increase the value of the α-coefficient. Therefore, after careful consideration, these two items were deleted from this measurement. After removing the two items, the internal reliability of this measurement contains a Chronbach's alpha of .70. Furthermore, **market- and technological turbulence** are included as control variables that have a potential effect on the radical innovation performance of a company ($\alpha = .47$ and $\alpha = .81$). Both measurement items are adopted from Jaworksi and Kholi (1993). The market turbulence measurement item evaluates the degree to which the construction and preferences of a company's customers tends to change over time. Whereas the technological turbulence refers to the speed of which technology is evolving within in the industry. Both variables have a potential effect on radical innovation, as they

could pressure a company to innovate quicker. As a result, incremental innovation is a more likely result rather than radical breakthroughs. Therefore, the both 4-item composite measurements are included to control for potential effects on radical innovation. Yet, the Chronbach's alpha of market turbulence also does not meet the minimum required value of .70. Therefore, suggested by the statistical analysis, two items were deleted from the composite measurement to achieve the most reliable construct possible. After removing these two items, the Chronbach's alpha reached a value of .64. This measurement is still included in the statistical analysis. In fact, Pallant (2010) discusses that it may be difficult to measure a decent Cronbach's Alpha when the scale contains less than 10 items. As this measurement currently contains two items, there is reason to believe that there is still internal reliability in the composite measurement.

Moreover, the **size of the company** will be assessed in terms of number of employees in FTE. Schulze and Hoegl (2008) clarify that the number of people within a company could potentially cause slow rigidity due to a complex structure, thereby constraining the capability to innovate. Furthermore, the **respondents' tenure** will be included (years in office) to control for potential respondent effects.

4.4 Analytical strategy

Following, different statistical analyses were conducted to test scale reliability, detect potential multicollinearity issues and perform hypothesis testing. First, data was manipulated to conduct this statistical analysis. In the current questionnaire, the wording of particular items was reversed to help prevent response bias. The data of these items has been inverted, by creating a new variable in opposites score to calculate the total score. Appendix A shows which items were reverse coded. Second, reliability of the scales is assessed by calculating the Cronbach's alpha. The Cronbach's alpha indicates de internal consistency of the items that make up the composite measurement whether they all measure the same underlying variable (Pallant, 2010). Nunnally (1978, as cited in Pallant, 2010) recommends a minimum value of 0.70 of Cronbach's alpha. However, Pallant (2010) elaborates that this value is very dependent on the number of items in the scale. Namely, if a scale consists of less than 10 items, the Cronbach's alpha could potentially turn out very small. The values of Cronbach's alpa are described in the measurement section above and in Appendix A. A factor analysis it not performed, as the sample size is too small to get reliable values. Pallant (2010) explains that there is a lot of controversy about the

required size to perform a factor analysis, but the minimum value is at least n = 150. Third, the descriptive statistics are presented of the sample data. In this section, the correlation matrix between the different variables is presented. Additionally, the generalizability of the sample to the population is assessed. Fourth, potential multicollinearity issues are detected by calculating the variance inflation factor (VIF). Pallant (2010) states that a VIF above 10 indicates multicollinearity problems. Following, the results of the multiple linear regression are presented to test the hypothesis. First, the independent variable is regressed on the mediating variable. Second, the independent variable and mediating variable are regressed on the dependent variable. Third, the independent variable is regressed on the dependent variable. The arithmetic means of the composite constructs are calculated to conduct the regression analysis, following the procedure of Schulze and Hoegl (2008). Last, a multiple regression is performed by combining the different models and hypotheses, shown in appendix B. This to see whether two behavioural processes of Nonaka mediate the relationship between a company's existing knowledge base and radical innovation together.

5. Results

The results of the statistical analysis are described in this chapter. The chapter starts with the descriptive statistics of the sample data, including a correlation matrix and the assessment of the generalizability to the population. Following, a multiple linear regression is performed to test the hypothesis. Performing collinearity numbers for the regression analysis show that all variance inflation factors are below 3, indicating that there is no deformation of results due to correlation among independent variables. Last, the results of the multiple regression analysis of the hypotheses combined are listed and explained in Appendix B.

5.1 Descriptive statistics

In order to understand the data better, a correlation matrix and descriptive statistics of all the variables are presented in table 2. This way, it is possible to get a clear view about the characteristics of the sample and to assess the relationship between the variables.

	1	2	3	4	5	6	7	8	9	10	12	13
1. Knowledge Breadth	1											
2. Knowledge Depth	.645**	1										
3. Radical Innovation	.419**	.481**	1									
4. Socialization	.208	.229*	.,293**	1								
5. Externalization	.364**	.398**	.390**	.385**	1							
6. Internalization	.291**	.250**	.415**	.490**	.645**	1						
7. Combination	.554**	.449**	.500**	.505**	.564**	.714**	1					
8. Competition Intensity	.168	.021	-.071	.064	.075	.079	.122	1				
9. Market Turbulence	.202	-.013	.112	.222*	.151	.247*	.344**	.365*	1			
10. Technological Turbulence	.270*	.182	.180	.347**	.382**	.416**	.401**	.175	.509**	1		
11. Size	.007	-.054	-.076	-.145	-.162	-.166	-.095	.144	.078	-.132	1	
12. Tenure	-.036	-.019	.008	.342**	.099	.065	.090	-.339**	.053	.302**	-.067	1
Descriptive statistics												
Mean	2.253	1.716	3.464	2.750	2.813	2.908	3.092	3.589	4.253	3.221	3.215	12.433
Standard Deviation	.985	.623	1.386	1.195	1.154	1.357	1.374	1.055	.931	1.297	1.205	10.510

**. Correlation is significant at 0.01 level (2-tailed).
*. Correlation is significant at 0.05 level (2-tailed).
N= 79

Table 2: Correlation matrix and descriptive statistics

Table 2 shows that there are several correlations that are remarkable as they have a value higher than, or close to .550. These correlations are: knowledge breadth and knowledge depth, combination and knowledge breadth, internalization and externalization, combination and externalization and combination and internalization. These relative high correlations could potentially pose as risk for

multicollinearity in the regression. However, Pallant (2010) elaborates on a higher acceptable threshold than 0.55. In fact, he discusses that correlation occurs when correlations exceed the value of .90 or higher. Furthermore, the above-mentioned correlations with a relative high value are not tested in the same regression model to test the hypotheses, which takes out the concern of multicollinearity. Yet, this does not apply to every correlation. Indeed, combination and knowledge breadth are present in one regression model. Therefore, the variance inflation factors (VIF) are calculated of all variables in the models. All VIF-values are below 3.0, which means that the risk of multicollinearity is acceptably low. For example, the VIF-value of combination and knowledge breadth is 1.107. Further potential multicollinearity effects will be discussed in the section of the regression analysis.

Table 3 shows the distribution of sample firms based on size (small, medium or large), the tenure of the respondent and in which sub-industries they are operating in.

Variable	**Count**
Size total	79 out of 81 (97,5%)
Small (< 50 FTE)	56/79 (70,8%)
Medium (50 – 250 FTE)	15/79 (19,00%)
Large (>250 FTE)	8/79 (10,2%)
Tenure total	79 out of 81 (97,5%)
0 – 9 years	37/79 (46,8%)
9 – 17 years	19/79 (24,1%)
17 – 26 years	16/79 (20,3%)
26 – 34 years	2/79 (2,5%)
34 – 43 years	5/79 (6,3%)
Sub-industry total	79 out of 81 (97,5%)
SBI 21.1 (Manufacturing of pharmaceutical raw materials)	1/79 (1,3%)
SBI 21.2 (Manufacturing of pharmaceutical products)	29/79 (36,7%)
SBI 72.11.2 (Biotechnological R&D in the field of medical products, pharmaceutical processes and food)	19/79 (24,1%)
SBI 26.6 (Manufacturing of radiation appliances and electro-medical and electrotherapeutical appliances).	12/79 (15,1%)
Other	18/79 (22,8%)

Table 3: Sample characteristics distribution

The majority of the sample companies are small-sized, namely 70,8%. This means that these companies employ less than 50FTE. Furthermore, 22,8% of the sample companies indicated that they operate in another industry than the four provided options. Yet, the respondents textual filled in what the main activity of the company was. After careful assessment of these answers, it is decided that these activities

definitely fall under the manufacturing of products within the Life Sciences and Health-industry. Second, a valid source is used to obtain the contact details of the companies, namely the Chamber of Commerce. All companies contacted to fill in the questionnaire categorize in one of the four given options as they are listed under these sub-industries in their registration at the Chamber of Commerce. However, it is reasonable to believe that the respondent does not have knowledge about the sub-industry it was registered upon establishment. Therefore, the respondents that selected 'other' are not disregarded as valid respondents.

Table 4 shows the distribution in sub-industries of both the sample companies and the population companies.

Sub-industry	**Observed N**	**Expected N**	**Change**
Manufacturing of pharmaceutical raw materials (SBI-code 21.1)	1 (1,3%)	3,6 (4,6%)	- 2,6
Manufacturing of pharmaceutical products (SBI-code 21.2)	30 (38,0%)	32,2 (40,8%)	- 2,2
Biotechnological R&D in the field of medical products, pharmaceutical processes and food (SBI-Code: 72.11.2)	19 (24,1%)	26,8 (33,9%)	- 7,8
Manufacturing of radiation appliances and electro-medical and electrotherapeutical appliances (SBI-code: 26.6)	11 (13,9%)	16,4 (20,7%)	- 5,4
Other	18 (22,7%)	0	+ 18
Total	79 (100%)	79 (100%)	0

Table 4: Sample versus population sub-industry distribution

Unfortunately, this is the only demographic characteristic available for comparison as the Chamber of Commerce does not provide additional information when purchasing a contact list. For example, it is unknown how many companies within the industry fall in the different size groups. Therefore, the representativeness of the sample for the population is based on the amount of economically active companies within the different sub-industries of the Life Sciences and Health sector. The analysis shows that there are certain differences among the amount of expected and observed observations within the

sub-industries. However, the ‘other’-option could be potentially distributed among the four sub-industries to lift these differences. Yet, the author does not contain sufficient knowledge to distribute these respondents over the four sub-industries. E.g. “medical devices” could be distributed among SBI code 26.6 but also among 72.11.2 and 21.2. In conclusion, although there are small discrepancies among expected and observed observations, it is possible to assume that the ‘other’ 18 respondents could explain these differences. Moreover, the discrepancies are rather minor. Additionally, the sample list was not completed as companies were excluded that are not willing to share their contact details Additionally, multiple scholars touch upon the number of participants necessary to generalize the findings over a population. Stevens (1996) asserts that for every predictor in a conceptual model, 15 participants are needed. If this includes the mediating variables, this means that this study requires 15 * 6 predictors = a minimum of 90 participants. Furthermore, Tabachnick and Fidell (2007) argue that there is a formula to calculate the minimum required sample size, namely: $N > 50 + 8m$, where N is the minimum number of participants required and m is the number of independent variables. 50 + (8*6) = 96 participants. This study acquired 81 participants, where two data-sets had to be removed, which indicates that this is not a sufficient amount to generalize the findings over a population. However, the number of participants is close to the theory of Stevens (1996). Moreover, the F-value is calculated in the statistical analysis to indicate the overall significance of the models with the available data. Therefore, based on the only available demographic of the sample and the minimum required amount of participant, it is reasonable to assume that the generalizability concerns of the sample are minimal.

5.2 Regression analysis

The mediating effects of the conceptual model are tested by developing several models through multiple regression. Multiple regression is used to assess the predictive capability of multiple independent variables on one continuous dependent variable (Pallant, 2010). A multiple regression analysis is conducted separately for the four hypotheses, following the procedure of Preacher and Hayes (2004) (See figure 8). First, the independent variable is regressed on the mediating variable, responding to model 1 in the tables. Second, the independent variable is regressed on the dependent variable, shown in model 2 in the tables. Third, the independent variable and mediating variable are regressed on the dependent variable, responding to model 3. The results are presented in table 5a up till and including table 5d. To make sure that valid conclusions are drawn, two additional analytical techniques were used, namely the Sobel test and the partial posterior method.

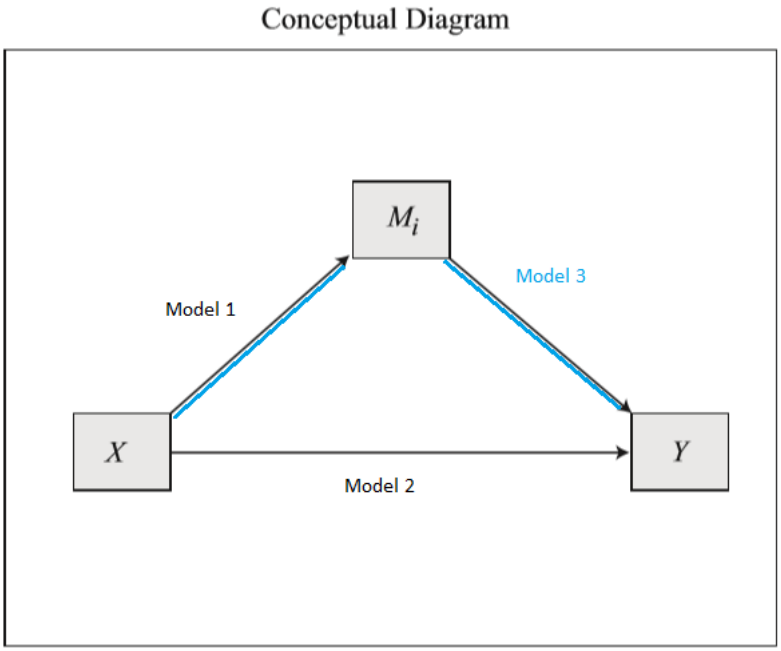

Figure 8: Multiple regression analysis to test mediating effects

5.2.1 Regression analysis Hypothesis 1

Dependent variable →	Externalization	Radical innovation	
	Model 1	Model 2	Model 3
Control variables			
Competition	.045	-.218	-.230
Technological turbulence	.260*	.066	-.006
Market turbulence	-.002	.228	.229
Size	-.133	-.051	-.014
Tenure	.003	-.009	-.010
Simple effects			
Knowledge depth	.626**	1.050***	0.875***
Externalization			.279*
R^2	.269	.269	.309
F-Value	4.419***	4.416***	4.521***
Sobel test (z-score)	-	-	1.6545
N	79	79	79

Note: The variance inflation factors range from 1.060 and 1.773

* p < 0,05. ** p < 0,01. *** p <0,001 (Two-tailed, sample size = 79)

Table 5a: Multiple Regression analysis hypothesis 1

Every hypothesis has been tested in different multiple regression models. First the independent variable is tested on the mediating variable (see model 1). Following, the direct effect of the independent variable is regressed on the dependent variable (see model 2). Last, both the mediating variable and independent variable are regressed on the dependent variable (see model 3). In order to test the hypothesis, the potential mediating variable is introduced in model 3 to see if that would reduce or eliminate the significance of the independent variable. With hypothesis 1 it is considered that externalization positively mediates the relationship between knowledge depth and radical innovation. Model 1 shows that the independent variable is significant on the mediating variable (β = 0.626, $p < 0.001$, model 1), see table 5a. Moreover, there is a direct effect of the independent variable on the dependent variable (β = 1.050, $p = 0.006$, model 2). The results indicate that after the introduction of externalization into the regression model, the coefficient for knowledge depth remains significant (β = 0.875, $p = 0.007$, model 3) and the externalization has a significant effect on radical innovation (β = 0.279, $p < 0.05$, model 3). However, the explanation power of model increased from a R^2 of .269 to .309, after introducing the mediating variable. Moreover, the significance of the independent variable is reduced with 0.001 in

model 3, indicating a partial mediating. The discriminant F-value is significant in model 3, making it possible to perform a Sobel test to confirm these findings. The Sobel test seems to be insignificant (z = 1.6545, $p = 0.098$). However, Falk and Biesanz (2015) discuss that the Sobel test has a lower power than other statistical analysis to test mediation effect. Therefore, another analysis is conducted to see if the indirect effect of knowledge breadth on radical innovation is significant. A p-value is calculated by the partial posterior method (Biesanz, Falk and Savelei, 2010). The partial posterior method is newly developed statistical approach with relative high power. In comparison to more traditional approaches, the partial posterior method is controlled for Type I errors. This means the improper rejection of a true null hypothesis. The partial posterior indicates the significance of the relationship of the independent variable on the mediating variable and the mediating variable on the dependent variable together. After performing this test, the significance of this combined relationship is $p = 0.036$. In sum, this result provides evidence that there is a mediating effect, partially supporting hypothesis 1.

5.2.2 Regression analysis Hypothesis 2

Dependent variable →	Internalization	Radical innovation	
	Model 1	Model 2	Model 3
Control variables			
Competition	-.026	-.218	-.209
Technological turbulence	.353*	.066	-.048
Market turbulence	.142	.228	.182
Size	.-172	-.051	.005
Tenure	-.007	-.009	-.007
Simple effects			
Knowledge depth	.397	1.046***	.921***
Internalization			.324**
R^2	.225	.269	.347
F-Value	3.482**	4.416***	5.382***
Sobel test (z-score)	-	-	1.412
N	79	79	79

Note: The variance inflation factors range from 1.060 and 1.781

* p < 0,05. ** p < 0,01. *** p <0,001 (Two-tailed, sample size = 79)

Table 5b: Multiple Regression analysis hypothesis 2

A similar regression model is performed in table 5b. Hypothesis 2 proposes that internalization positively mediates the relationship between knowledge depth and radical innovation. Model 1 shows that the coefficient for knowledge depth on internalization is insignificant (β = 0.397, *p* = 0.092, model 1). The independent variable, knowledge depth, is significant on radical innovation (β = 1.046, *p* = 0.000, model 2). After introducing the mediating variable, internalization, in this model, the independent variable coefficient is still significant (β = .921, *p* = 0.001, model 3), but the significance did reduce from 0.000 to 0.001. Moreover, the Sobel test is insignificant (z = 1.4121, *p* = 0.158). In order to prevent a Type I error, the partial posterior approach is used (*p* = 0.070). This means that there is no significant indirect relationship of knowledge depth through internalization on radical innovation. In conclusion, hypothesis 2 is not supported.

5.2.3 Regression analysis Hypothesis 3

Dependent variable →	Socialization	Radical innovation	
	Model 1	Model 2	Model 3
Control variables			
Competition	.1384	-.261	-.301
Technological turbulence	.119	.094	.059
Market turbulence	.095	.095	.067
Size	-.164	-.072	-.023
Tenure	.038**	-.010	-.021
Simple effects			
Knowledge breadth	.183	.582***	.528***
Socialization			.296**
R^2	.234	.2133	.263
F-Value	3.666*	3.254*	3.620**
Sobel test (z-score)	-	-	1.0938
N	79	79	79

Note: The variance inflation factors range from 1.067 and 1.628

* p < 0,05. ** p < 0,01. *** p <0,001 (Two-tailed, sample size = 79)

Table 5c: Multiple Regression analysis hypothesis 3

The results of the multiple regression to test hypothesis 3 are shown in table 5c. Unfortunately, there is no significant relationship between knowledge breadth and socialization (β = 0.183, p = 0.169, model 1). There is a direct relationship between the independent variable, knowledge breadth, and radical innovation (β = 0.582, p = 0.003, model 2). When introducing the mediating variable into the regression, the independent loses some significant (β = 0.528, p = 0.009, model 3) and socialization has a significant, positive effect on radical innovation (β = 0.296, p < 0.01, model 3). Moreover, the explanation power of the model only increases marginally after introducing the mediating variable (R^2 = .234 in model 1, R^2 = .263 in model 3). The z-score of the Sobel test remains insignificant (z = 1.096, p = 0.274). The partial posterior approach confirms this (p = 0.142). In conclusion, there is no support for hypothesis 3.

5.2.4 Regression analysis Hypothesis 4

Dependent variable →	Combination	Radical innovation	
	Model 1	Model 2	Model 3
Control variables			
Competition	-.040	-.261	-.244
Technological turbulence	.175	.094	.023
Market turbulence	.264	.095	-.012
Size	-.123	-.072	-.022
Tenure	.004	-.010	-.012
Simple effects			
Knowledge breadth	.670***	0.582***	.311
Combination			.405**
R^2	.401	0.213	.310
F-Value	8.031***	3.254**	4.556***
Sobel test (z-score)	-	-	2.630**
N	79	79	79

Note: The variance inflation factors range from 1.067 and 1.699

* p < 0,05. ** p < 0,01. *** p <0,001 (Two-tailed, sample size = 79)

Table 5d: Multiple Regression analysis hypothesis 4

Last, the results of the multiple regression to test hypothesis 4 are shown in table 5d. First, there is a significant relationship between knowledge breadth and combination (β = 0.670, $p < 0.001$, model 1). Furthermore, there is a direct relationship between knowledge breadth and radical innovation (β = 0.5820, $p = 0.003$, model 2). After introducing the mediating variable, namely combination, into the regression, the independent variable is insignificant (β = 0.311, $p = 0.071$, model 3). Therefore, there is reason to believe that combination fully mediates the relationship between knowledge breadth and radical innovation. The results of the Sobel test confirm these results with a significant value (z = 2.630, $p < 0.01$). The partial posterior approach also shows a significant mediating effect ($p = 0.001$) In conclusion, hypothesis 4 is fully supported. A summary is given in table 6.

5.2.5 Summary hypothesis testing

Hypothesis	Findings
Hypothesis 1: Externalization positively mediates the relationship between a company's deep knowledge base and radical innovation.	Partially supported
Hypothesis 2: Internalization positively mediates the relationship between a company's deep knowledge base and radical innovation.	Not supported
Hypothesis 3: Socialization positively mediates the relationship between a company's broad knowledge base and radical innovation.	Not supported
Hypothesis 4: Combination positively mediates the relationship between a company's broad knowledge base and radical innovation.	Fully supported

Table 6 results of hypothesis testing

5.3 Additional regression analysis

After testing the models separately, it was explored whether the models could be tested together. However, the models shown instability when tested together. The sample size (n=79) is relatively small, as it contains limited variation of the dependent variable. Therefore, when testing all variables in one model, the model has the risk of being over-specified. To prevent over-specification of the model, the models are tested separately. The combined models show that when the models are combined, a certain kind of instability occurs in the variables. The models and the explanation of the instability are explained in Appendix B. This instability could be caused by the high correlation between externalization and internalization (r = .645, p < 0.01) or the relatively high correlation between combination and socialization (r = .505, p < 0.01) and potential multicollinearity issues between these mediating variables. The standard solution to reduce multicollinearity is to remove variables from the model.

6. Discussion

The main objective of this study is to investigate how different knowledge bases of a company could result in radical innovation. There are contradicting perceptions whether the breadth of depth of a company's knowledge base contributes to radical innovation (Zahra and George, 2002; Laursen and Salter, 2006; Leonard-Barton, 1992; Zhou and Li, 2012; Taylor and Greve, 2006). The Life Sciences and Health Industry of the Netherlands is used to examine the mediating relationships of four different behavioural processes between knowledge bases and radical innovation. This study proposed that knowledge depth could result in radical innovation, through behavioural processes as externalization or internalization. The results show that externalization partially mediates the relationship between a company's deep knowledge base and radical innovation, supporting hypothesis 1. This means that there are probably other unknown variables are mediating in the model, as externalization only partially mediates this relationship. Furthermore, a significant mediating effect of combination was found between the relationship between a broad knowledge base and radical innovation. These findings critically challenge the findings of Schulze and Hoegl (2008). As they found that both externalization and combination have a negative effect on novel product ideas, the starting phase of an innovation process. However, this study's results show that radical innovation benefits from externalization and combination when the knowledge base is taken into account.

However, two hypotheses could not be supported based on this sample data. This study proposed that internalization positively mediates the relationship between a company's deep knowledge base and radical innovation. The acquirement of tacit knowledge through experimenting helps individuals to develop and seek opportunities beyond their own personal experience (Dougherty, 1992). It was projected that companies with a deep knowledge base could overcome deep-rooted routines by sparking new insights through internalization. Unfortunately, this effect is not found in this study, but still offers valuable insights for future research. Schulze and Hoegl (2008) found a positive effect of internalization on novel product ideas, which could indicate that the knowledge depth is a potential obstacle to fully utilize the behavioural process of internalization. Indeed, Laursen and Salter (2006) elaborate that a company with a deep knowledge base lacks the experience to solve difficult problems in the implementation phase. One may think that a company benefits from internalization in the idea phase of

radical innovation, but perhaps does not add value in the implementation phase. Other factors, such as the quality of the internalization process could play an important role as well.

Additionally, no significant mediating effect of socialization was found between the relationship of a company's broad knowledge base and radical innovation. It is argued that a company with a broad knowledge base lacks sufficient coordination to fully execute ideas into radical innovation (Laursen and Salter, 2006). This study proposed that socialization is a form of knowledge sharing that could facilitate the combination of knowledge to detect new and unseen patterns in the existing broad knowledge. Consequently, this could lead to radical innovation. However, this hypothesis is not backed by the sample data of this study. Although a larger sample size would certainly help shine clarity on the matter, perhaps other factors have an influence on this relationship. It could be argued that this relationship is more complex and a second mediator should be included in the model. For example, it is logical to assume that there could be a second behavioural process where the newly discovered knowledge pattern, found in an informal environment, is discussed in a formal setting to take actionable steps to achieve radial innovation. Furthermore, other aspect could play a role in this relationship that were not taken into account in this study. For example, knowledge protective activities, such as signed non-disclosure agreements, could have a psychological moderating effect on freely sharing knowledge in informal settings.

Next to the tested hypothesized relationships, the results of this study found another interesting effect. Technological turbulence has a positive, significant effect on both externalization and internalization (See model 1 in table 5a and 5b). Technological turbulence measured the speed of which technology is evolving in the industry. These findings are not that surprising, as externalization and internalization are both behavioural processes where new knowledge is acquired. It is logical to assume that when technology is continuously updated in an industry, companies need to keep up with the technological trends. Interviewing experts or experimenting with the new technology is a logical consequence to do so. The following section will discuss the valuable theoretical and managerial contributions this study contains, both opposing and integrating with previous research.

6.1 Theoretical contributions

This contribution of this master thesis to the literature of innovation and knowledge management is threefold. First, although previous studies try to determine the role of knowledge in product innovation (Carayannis, Gonzales and Wetter, 2003; Chesbrough, 2003; Hurmelinna-Laukkanen, 2011; Katz and Du Preez, 2008; Leonard and Sensiper, 1998), a lot of opposing views still exist whether a company's deep or broad knowledge could result in radical innovation (Zahra and George, 2002, Laursen and Salter, 2006). This work contributes in this field as it provides more insights about the complex relationship between knowledge and innovation. The results of these study suggest the importance of the implementation of knowledge management processes based on the company's existing knowledge base to achieve radical innovation and avoid incremental innovation. This is partially in line with the findings of Zhou and Li (2012), who discuss that a broad knowledge base benefits more from knowledge sharing than knowledge acquisition and vice versa for companies with deep knowledge bases. However, this study's results also partially contradict these findings, as a company that contains knowledge breadth does not seem to benefit from socialization to achieve radical innovation. Socialization is a behavioural process where knowledge is shared within a company in an informal setting. On a similar note, a company with a deep knowledge base does not achieve radical innovation through internalization, where individuals acquire new knowledge through learning-by-doing. In conclusion, the insights gained from this study show that not every knowledge sharing- or acquisition process is beneficial for company's knowledge base to achieve radical innovation.

Second, this research is the first to test through which concrete behavioural processes a company's existing knowledge base could result in radical innovation. The study proves that a company's knowledge base is an important antecedent to take into consideration in the complex relationship between knowledge management and radical innovation.

Third, this research builds upon the findings of Schulze and Hoegl (2008) to see whether the four behavioural processes of Nonaka (1994) could lead to radical innovation rather than just novel idea generation. Moreover, it tests if these processes are significant mediators to transfer the depth or breadth of knowledge into radical innovation. Schulze and Hoegl (2008) found that socialization and

internalization are positively related to novel product ideas. However, this study's findings show that they do not lead to radical innovation when a company's knowledge base is included in the relationship. This could mean that these two behavioural processes are not beneficial in the implementation phase of radical innovation, or that the effectiveness of these processes should always be assessed with the current knowledge base of a company.

Furthermore, Schulze and Hoegl (2008) also found a negative relationship between externalization and combination with novel product ideas, whereas this study found positive mediating effects between different knowledge bases and radical innovation. This offers some insights that these behavioural processes could be very valuable in a later stage of the innovation process or that these are beneficial when the knowledge base of a company is taken into account. Further research could address these insights to see if the behavioural processes have changing effects in different stages of the product innovation processes and the effect of knowledge bases in these stages.

6.2 Managerial implications

In addition to the theoretical contributions, this study also provides practical implications for managers. Findings of this study could potentially serve as guidance in order to establish and develop radical innovation. Therefore, it is evident that managers assess their current knowledge base to see if the structure and content reflects breadth or depth. Companies with a broad knowledge base should foster combination and companies with a deep knowledge base should implement externalization in order to realize radical innovation.

Managers of companies with a deep knowledge base can boost externalization, e.g., by stimulating the use of expert interviews and sharing insights and knowledge gained from a previous project. This way, a company with a deep knowledge breaks out from their observational slowness and rigid cause-and-effect understanding, expands the diversity of knowledge domains and actively explores new technological and market opportunities.

Additionally, managers of companies with a broad knowledge base can encourage combination, which means actively spreading existing knowledge through presentations, documents, telephone

conversations, meetings or communication networks. New discovered patterns could generate breakthrough innovations and the documented aspect of combination provides easy access to knowledge through all departments and levels of the company.

This way, managers and board members could profit of these findings by maximizing the advantages of their knowledge resources and realize radical innovation.

6.3 Limitations and further research

This study contains certain limitations that future work can address. First, the relative small sample size and the fact that this study is cross sectional makes it difficult to fully measure causality. It is suggested that future research should adopt a longitudinal approach and assign a larger sample to increase the ability to fully test causal relationships. Second, the sample of this study is situated in one industry in the Netherlands and limited sample characteristics are available to the author. This way, it is difficult to generalize the findings of the study internationally or across different industries. Therefore, additional research is encouraged to adopt a multi-industry approach in different parts of the world. Third, although the composite measurement of radical innovation is used in previous studies (Zhou and Li, 2012; Atuahene-Gima, 2005), the results obtained from the questionnaire are still perceptual and derived from an one-respondent approach. It should be considered that a potential response bias is present, where respondents tend to overestimate the company's capabilities. Consequently, further research should address these concerns by including objective measurements, such as patents or multiple respondents per questionnaire.

Ensuing the suggested improvement of forgoing limitations, further research is encouraged to address relevant questions and explore additional research opportunities. One such question could be the potential effect of knowledge protective activities on the relationship of the behavioural processes and radical innovation. As knowledge exchange carries the significant risk to lose competitive advantage, it would be interesting to investigate the psychological effect of knowledge protective activities of company, both internally and externally (Hurmelinna-Laukkanen, 2011). It would be logical to assume that this has a potential effect on behavioural processes such as socialization and externalization. Furthermore, this study focuses on the perceptual intensity of the behavioural processes within a

company. Perhaps, it would be interesting to conduct a qualitative analysis in terms of in-depth interviewing and observing to include the quality of the behavioural processes, rather than the (perceptual) frequency. Last, as there are conflicting views about the benefits of usage of socialization and internalization, it would be interesting to investigate the effect of the four behavioural processes on the implementation phase of product innovation.

7. Appendices

Appendix A: Measurement Scales

Scale: 1 = strongly agree, 2 = agree, 3 = somewhat agree, 4 = neither agree nor disagree, 5 = somewhat disagree, 6 = disagree, 7 = strongly disagree	
Variable	**Items**
Knowledge breadth *Chronbach's α = 0.80*	1. We possess market information from a diversified and wide-ranging customer portfolio. 2. We have accumulated knowledge of multiple market segments. 3. Our R&D expertise consists of knowledge from a variety of backgrounds.
Knowledge Depth *Chronbach's α =0.85*	1. We are highly familiar with this industry. 2. We have acquired a great deal of experience about this industry. 3. The knowledge of our firm in this industry is thorough. 4. We have in-depth knowledge about the technology in this industry. 5. We have thorough understanding and experience of current customers. 6. We have accumulated in-depth knowledge of the key market segments that we focus on. 7. Our R&D expert have thorough technical knowledge and skills within our specialized domain.
Radical innovation *Chronbach's α =0.84*	1. Our company frequently introduces products that are radically different from existing products. 2. Compared to your major competitor, our company introduced more radical product innovations in the last three years. 3. Percent of total sales from radical innovations introduced in the last three years (less than 1%, 1-5%, 6-10%, 11-15%, 16-20%, 21-15%, over 25%).* 4. In the past, we introduced innovation that involves a fundamentally major improvement over the previous technology. 5. In the past, we introduced innovation that leads to products that are difficult to replace with substitute using older technology. 6. In the past, we introduced innovation that leads to products that bring in substantial transformation in consumption patterns in the market.
Socialization *Chronbach's α =0.88*	1. We spent a lot of time in personal interaction aside from organized meetings with other people in the team in order to discuss suggestions, ideas or solutions. 2. We spent a lot of time in personal interaction aside from organized meetings with people from other departments in the company in order to discuss suggestions, ideas or solutions. 3. We spent a lot of time in intense discussions about suggestions, ideas, or solutions in face-to-face meetings with people from other departments in the company. 4. We spent a lot of time in the conscious creation of a common understanding of a problem with people from other departments in the company.

Externalization *Chronbach's α =0.86*	1. We spent a lot of time reflecting collectively and framing our ideas or solutions with regard to customer needs. 2. We spent a lot of time interviewing competent people about ideas or solutions with regard to relevant technologies. 3. We spent a lot of time interviewing competent people about ideas or solutions with regard to customer needs. 4. We spent a lot of time creating detailed descriptions (e.g. protocols, presentations, reports) containing newly developed knowledge about customer needs.
Combination *Chronbach's α =0.93*	1. We spent a lot of time systematically editing newly gained technological knowledge. 2. We spent a lot of time systematically editing newly gained insights regarding customer needs. 3. We spent a lot of time systematically editing the newly gained knowledge about the procedure of creating new product ideas. 4. Within the organization, we distribute our newly gained insights about customer needs.
Internalization *Chronbach's α =0.87*	1. We spent a lot of time in trial-and-error (experimenting) thereby developing a sense for the feasibility of our thoughts regarding the functionality of the technology. 2. We spent a lot of time in trial-and-error (experimenting) thereby developing a sense for the feasibility of our thoughts regarding customer needs. 3. We spent a lot of time trial-and-error (experimenting) thereby developing sense for the feasibility of our thoughts regarding the procedure of creating novel product ideas. 4. We spent a lot of time systematically testing our theoretical knowledge about customer needs.
Competition *Chronbach's α =0.70*	~~1. There are many "promotion wars" in our industry.~~ ~~2. Anything that one competitor can offer, others can match readily.~~ 3. Price competition is a hallmark of our industry. 4. Our competitors are relatively weak.*
Market turbulence *Chronbach's α =0.47*	1. In our business, product preferences change quite a bit over time. 2. Our customers tend to look for new products all the time. ~~3. We are witnessing demand for our products from customers who never bought them before.~~ 4. ~~We cater to many of the same customers that we used to in the past.*~~
Technological turbulence *Chronbach's α =0.81*	1. The technology in our industry is changing rapidly. 2. Technological changes provide big opportunities in our industry. 3. A large number of new product ideas have been made possible through technological breakthroughs in our industry. 4. Technological developments in our industry are rather minor.*

* These items were reverse coded to conduct the statistical analysis.

Appendix B: Additional regression models

B.1 Multiple regression of hypothesis 1 and 2 combined

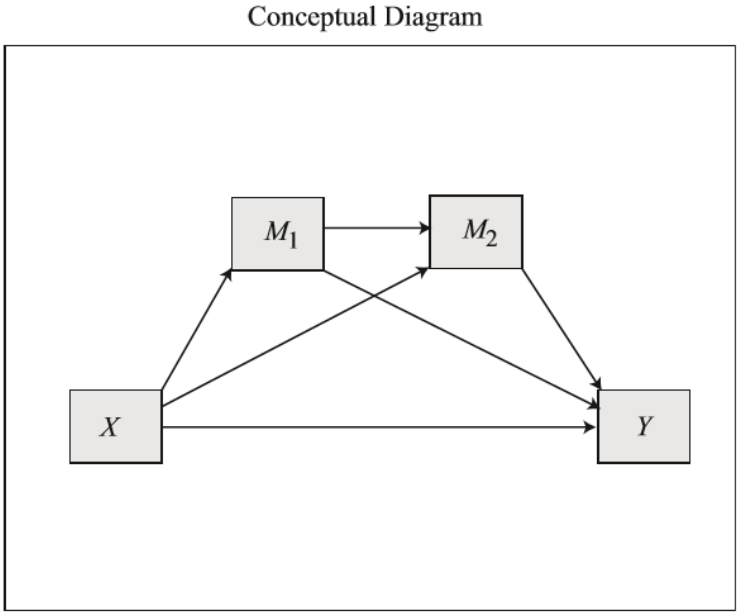

Figure 9: Multiple regression analysis to test double mediating effects

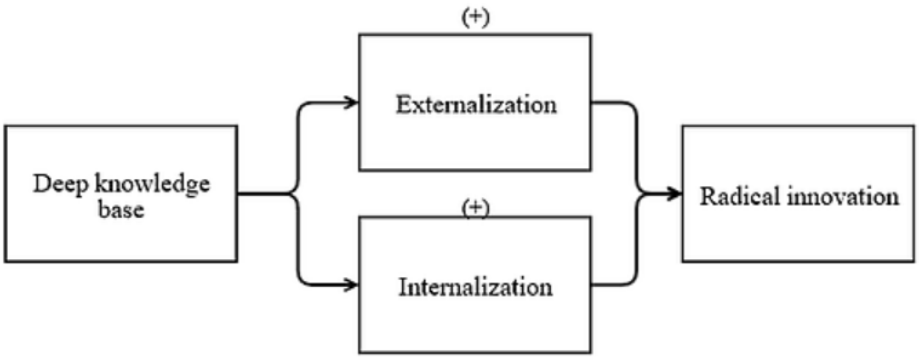

Figure 10: The conceptual model of hypothesis 1 and 2 combined

Dependent variable →	Externalization	Internalization	Radical innovation	
	Model 1	Model 2	Model 3	Model 4
Simple effects				
Knowledge depth	0.626**	-.218	1.050***	0.881**
Externalization		.670***		.894
Internalization				.2827*
R^2	.269	.462	.269	.350
F-Value	4.414**	8.705***	4.416***	4.701**
N	79	79	79	79

* p < 0,05. ** p < 0,01. *** p <0,001 (Two-tailed, sample size = 79)

Table 7a: Multiple Regression analysis combined model hypothesis 1 and 2

The conceptual model in figure 5 could also be interpreted that both externalization and internalization mediate the relationship between knowledge depth and radical innovation. Therefore, an additional analysis has been conducted to see if the models could be combined, following the procedure of Preacher and Hayes (2004), see figure 9. Naturally, it is expected that there is no relationship between the mediating variables as this is not the core of this study, see figure 10. Table 7a shows the results of the multiple regression of the first combined conceptual model. Model 1 represents the independent variable, knowledge depth, regressed on the first mediator, namely externalization. Following, both the independent variable and first mediating variable are regressed on the second mediating variable, namely internalization, shown in model 2. Model 3 shows the result of the direct effect of the independent variable on the dependent variable, radical innovation. Lastly, model 4 represents the full model where the independent variable and both mediating variables are regressed on the dependent variable. The instability of this combined model is shown in the lack of significance of the relationship between externalization and radical innovation when internalization is introduced. In model 4, table 7a the coefficient of externalization on radical innovation is insignificant ($\beta = 0.894$, $p = .584$, model 4). However, without internalization in the model this coefficient is significant ($\beta = 0.279$, $p = .484$, model 3, table 5a). If externalization was independent of internalization, than this coefficient should be significant in both models. However, this is not the case. Due to this instability, the models were tested separately.

B.2 Multiple regression of hypothesis 3 and 4 combined

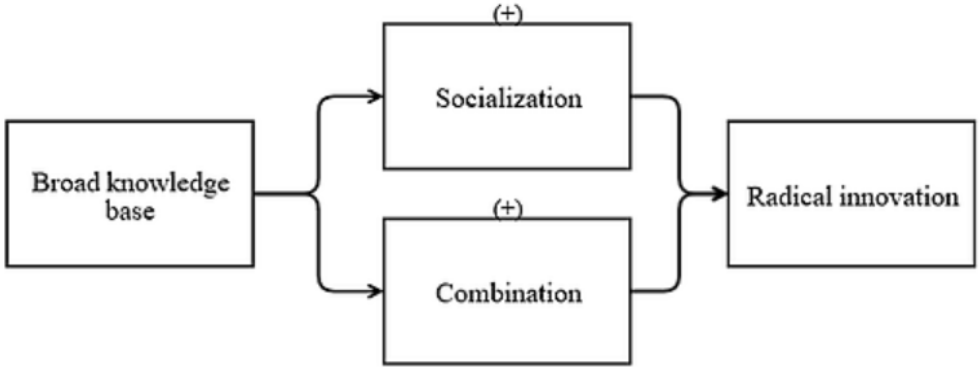

Figure 11: The conceptual model of hypothesis 1 and 2 combined

Dependent variable →	Socialization	Combination	Radical innovation	
	Model 1	Model 2	Model 3	Model 4
Simple effects				
Knowledge breadth	.183	.591***	.582***	.349
Socialization		.431***		.147
Combination				.434*
R^2	.234	.509	.213	.302
F-Value	3.666**	10.503***	3.254***	4.119***
N	79	79	79	79

* p < 0,05. ** p < 0,01. *** p <0,001 (Two-tailed, sample size = 79)

Table 7b: Multiple Regression analysis combined model hypothesis 3 and 4

Table 7b shows the results of the multiple regression of the second combined conceptual model, see figure 11. Following a similar procedure of the first combined regression: Model 1 represents the independent variable, knowledge breadth, regressed on the first mediator, namely socialization. Following, both the independent variable and first mediating variable are regressed on the second mediating variable, namely combination, shown in model 2. Model 3 shows the result of the direct effect of the independent variable on the dependent variable, radical innovation. Lastly, model 4 represents the full model where the independent variable and both mediating variables are regressed on the dependent variable. The instability of this combined model is shown in the lack of significance of the relationship between socialization and radical innovation when combination is introduced. In fact, in model 4, table 7b the coefficient of socialization on radical innovation is insignificant (β = 0.434, *p* = .311, model 4). However, without combination in the model this coefficient is significant (β = 0.296, *p* = .032, model 3, table 5c). If socialization was independent of combination, than this coefficient should be significant in both models. However, this is not the case. Due to this instability, the models were tested separately.

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